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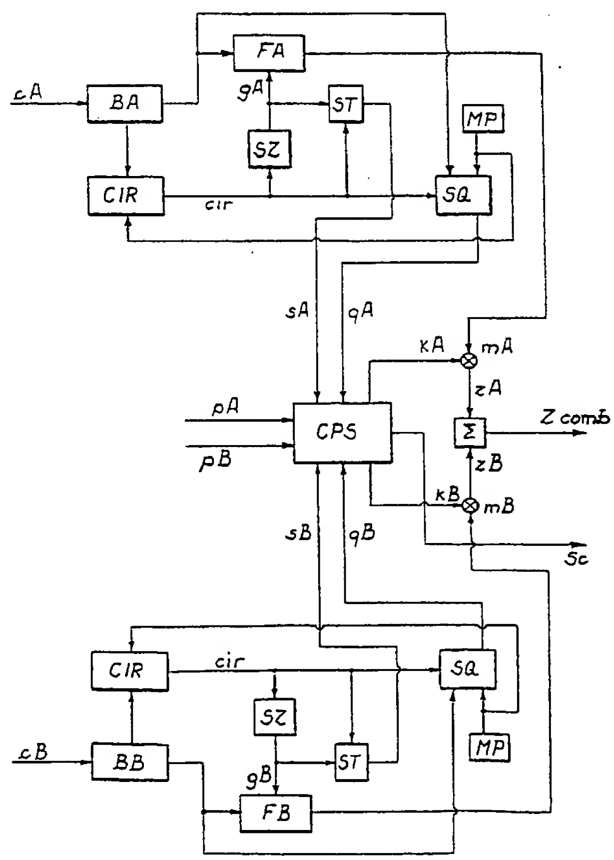
(54) Title: SPACE-DIVERSITY DIGITAL RADIO MOBILE RECEIVER AND RELEVANT PROCESS

(57) Abstract

An adaptive receiver for time-division digital signals in a digital radio mobile system is inclusive of two or more branches receiving the signals substantially not correlated coming from the same number of antennae (A, B). The signals of each branch, coded in digital form after demodulation and sampling, are used for estimating the channel impulse response (CIR) and producing parameters (sA, qA, sB, qB) which are processed with signals (pA, pB) representative of the power received on each branch. Thus two signals (Zcom, Sc) are obtained and they control an equalizing element (EQZ) for the reconstruction of the received signal. The combination process provides for the estimation of the channel impulse response on each of the channels received, for their matched filtering and for the addition of the resulting signals, weighed in proportion to the power level and to a quality factor with which each signal has been received.



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SPACE-DIVERSITY DIGITAL RADIO MOBILE RECEIVER AND RELEVANT PROCESS

DESCRIPTION

This invention covers a process for the equalization, or else the correction of the distortions, respectively in phase and/or amplitude, of time-division digital signals in a radio mobile system, in which the radio signals are received by two antennae at least.

Furthermore the invention refers to a signal receiving device in radio mobile systems and more specifically an adaptive receiver of the type providing for the combination of the signals received by two or more antannae for time-division digital communication, in particular for a digital radio mobile system.

In a digital radio mobile system, the signal of a user is coded in a digital form and the information relating to a certain number of users, for instance eight users, is multiplexed with time division in order to form a frame where each user is assigned a time slot containing a train of bits (burst).

The signal thus formed will modulate the phase of a carrier wave, for instance with a constant envelope modulation or GMSK (Gaussian Minimum Shift Keying) phase modulation and each radio mobile receiver will extract only the relevant information from this flow.

The signals received in a radio mobile system show some distortions due to different causes such as propagation through multiple paths, Doppler effects, local oscillator drifts. These

phenomena are emphasized further on in the event of digital signals having a relatively wide band, in the order of 200 KHz each channel. The receiver therefore is to provide for an equalization of the signal received in order to improve the quality of the communication.

According to the known technique, such equalization may be obtained by a transversal filter, with or without decision feedback, or else with a Maximum Likelihood Sequence Estimate (MLSE) utilizing a matched filter and a Viterbi processor. In lack of a proper equalization, the quality of the communication may be compromised even if the signal received is powerful enough.

On the other hand, the equalization techniques require certain power values in the signal received for their correct operation, while there is the need of keeping the transmission power within certain limits for various reasons, e.g. to prevent interferences between the various areas and to minimise the consumption and the dimensions of the mobile terminals. When the received signals have a power below the threshold value of the correction system, this is not able any longer to satisfactorily reconstruct the signal, thus causing a deterioration in the quality of the received signal.

It has been suggested that these inconveniences could be avoided by using space diversity techniques in digital radio mobile systems i.e. by using two or more signals received from the same number of antennae positioned in such a way as to make these signals uncorrelated. The systems used are simple extensions to the digital case of the techniques known for the diversity reception of analog signals and are not devoid of inconveniences and restrictions.

One of these systems provides for the combination at the maximum power, i.e. the timing of the signals received and their subsequent addition, in order to maximize the signal/noise ratio of the combined signal. This system is not obviously capable of

considering the distortion of the received signals which is a very important factor in multi-path propagation conditions.

According to another technique, switching is provided on the antenna that in turn is receiving the signal at the highest power level.

The selection criterion can alternately be based on a quality estimate, but this requires a complete receiver for each antenna.

The switching technique is also involving problems due to the switching transients which should be made to coincide with the inter-burst interval (i.e. between two subsequent bursts), considering also that the variation speed of the propagation conditions may be short as compared with the duration of the burst itself. Not even this technique may effectively allow for the distortion that the signal may show.

The purpose of this invention is to overcome the above mentioned restrictions and inconveniences of the known receivers and in particular to make an effective equalization possible, even when the signals received on the different antennae are subject to a high distortion.

These purposes are achieved through the invention consisting in a process for equalizing time-division digital signals in a radio mobile system, in which the radio signals are received by two antennae at least, featuring the fact of implying the following phases:

a) making an estimate of the channel impulse response for each of the received signals;
b) making a matched filtering of each received signal;
c) calculating some weighing coefficients as a function of the information relating to the reception conditions contained in parameters relevant to each channel;
d) generating a combined signal by summing the outputs of the matched filters weighed according to said weighing coefficients and generating a control signal with a similar weighed combination;

e) making an estimate of the numeric sequence transmitted by means of an equalization of the combined signal with the aid of such first control signal that selects the parameters affecting the equalization process.

The invention also consists of an adaptive receiver in space diversity for time-division digital signals in a digital radio mobile system, including at least two branches receiving and processing signals, substantially not correlated, received by the same number of antennae and in which the demodulated signals of said branches, sampled and coded in a binary form, are stored in corresponding buffers, featuring the fact of including a setup circuit the inputs/outputs of which are connected to an equalizing circuit for the reconstruction of the signal received, where the setup circuit generates a first control signal and a second combined signal obtained as weighed combinations of the inputs.

Some further characteristics of the invention are the subject of the dependent claims.

These and any further characteristics of the invention, as well as the relevant advantages, will result from the following specification of a preferred realization form, which is not restrictive as to the invention, shown in the attached drawings where:

Fig. 1 shows a general block diagram of a receiver of the type using two antennae;

Fig. 2 shows schematically the structure of a TDMA frame;

Fig. 3 shows the structure of unit PD in more details;

Fig. 4 shows a possible configuration of the front end receiver and of the baseband converter; and

Fig. 5 shows a diagram for the determination of the weighing coefficients.

The receiver according to the invention is of the so-called space-diversity type. With reference to the figures, and in particular to Fig. 1, it contains two antennae, respectively A

and B, located in positions far enough as to consider the signals thus received not correlated.

The signal received by each antenna provides for a numeric modulation of a linear type or such as to be approximated in a linear form (therefore including the known modulations PSK, QAM, MSK, GMSK). Such signal also contains, as shown in Fig. 2, a frame formed by eight subsequent time slots (0-7), each containing a train or burst of bits relating to a conversation channel. Each conversation channel, as shown for instance for channel n. 2, is subdivided in two equal parts MB1 and MB2 separated by a preamble PR which is actually placed in an intermediate position. The contents of the preamble are known to the receiver and used for the estimate of the impulse response of the communication channel (CIR) and for the consequent variation of the correction parameters of a matched filter.

Antenna A is connected to a unit RFA including a front end receiver and a baseband converter, on the outlet of which an analog signal is available in the form of two orthogonal baseband components, which is sampled and converted in an 8 bit digital signal (cA) by an analog-digital A/D converter. One local oscillator OL provides one or more frequencies for the demodulation. A pA signal, representing the power level of the signal received by antenna A, is also drawn from unit RFA.

A possible form of implementation of unit RFA is shown in Fig. 4 and contains a radio frequency receiver stage marked by RxA that amplifies the signal and carries it to the input of a demodulator DEM of the coherent type.

Antenna B is associated to a similar signal processing chain, defined also as channel B, the components of which have been marked with the same references already used for chain A, and also identified if necessary with index B, which produce the corresponding signals cB and pB relating to antenna B.

The signals from the two A/D converters and the signals pA and pB are carried as input to a circuit PD producing two signals as

output, respectively a first control signal Sc (containing information on the channel characteristics) and the combined signal Zcomb (containing the information transmitted).
The Zcomb signal is carried to an equalization element EQZ as input, with a subsequent estimate of the numerical sequence transmitted, consisting in a known way of a Viterbi processor or in case of another type of equalizer, such as for instance a transversal filter with decision feedback (DFE).
In addition to the Zcomb signal, a signal Sc is also applied to equalizer EQZ and supplies the information required to actuate, in a known way, the equalization functions themselves. These functions may be carried out through a Viterbi processor, the operating parameters of which are directly deducible, in a known way, from signal Sc. The equalizing element may be alternately implemented with other known techniques, for instance with a transversal filter with decision feedback (DFE), in which the tap gains are still deducible from the knowledge of Sc.
A preferred implementation of the PD circuit according to the invention will now be illustrated with reference to the diagram of Fig. 3.
The cA signal from the A/D converter of channel A is stored in a register of buffer BA. The samples of the preamble are extracted from buffer BA to be used for the Channel Impulse Response (cir) estimate in the unit marked CIR, obtained in a known way with the known preamble sequence contained in MP storage.
The coefficients gA of a matched filter FA are obtained from the cir signal, through a sorter unit SZ. Moreover, cir and gA generate, in a first ST unit, an sA signal corresponding to the time response of the transmission channel to a single-impulse. Exactly ST calculates the convolution between the cir response and the gA samples.
Furthermore a signal qA, which is representative of the quality of reception, is also calculated. The quality signal qA may be evaluated in different ways, and may be based, for instance, on

the correlation between signal received and known preamble sequence, and/or on the quadratic error between signal received and signal reconstructed according to the estimate itself. The calculation of the average quadratic error is made in a second SQ unit receiving as input the cir signal, the samples of message from buffer BA and the contents of a storage MP where the sequence of the preamble is contained. More exactly, SQ reconstructs the signal received, according to the estimated cir samples and the known preamble sequence, compares it with the corresponding part drawn from buffer BA and determines the deviation between them. The greater is the qA quality factor, the better is the estimate of the distortion undergone by the channel and therefore the better is the reconstruction that has been made of it.

Corresponding signals sB and qB are generated by channel B, which has a structure identical with that of channel A.

Furthermore a processing circuit CPS is provided to receive:

the sA and sB signals from the two corresponding ST units, representative of the impulse response of channels A and B, respectively (therefore including the contribution due to the relating matched filters);

the quality factors qA and qB from the two corresponding SQ units; and

the signals pA and pB, directly from the receiving stages RxA and RxB, representative of the power of the signal received by the antennae A and B, respectively.

Circuit CPS produces separately two weighing coefficients kA and kB, which are functions respectively of qA, pA and qB, pB, which are carried to the inputs of two multipliers mA and mB, respectively, which receive on the other inputs the outputs of FA and FB respectively, thus generating the weighed signals zA and zB.

The signal kA and kB are obtained with the following modalities, illustrated also with reference to the diagram of Fig. 5.

The inputs pA, qA, pB and qB of the circuit CPS are used for forming the signals kA and kB according to the general formula:

$$(kA,\ kB) = f\ (pA,\ qA,\ pB,\ qB) \qquad (i)$$

The regions I, II and III shown in Fig. 5 are delimited by the segments indicated by the following equations in the plane qA, qB:

$$1:\ qB = qA.H1 \qquad 2:\ qB = qA.(1/H1)$$
$$3:\ qB = qA-H2 \qquad 4:\ qB = qA + H2$$

where H1 and H2 are two such parameters that $0 < H1 < 1$ and $H2 > 0$.

The coordinates qA and qB determine in which of the regions I, II or III corresponds to the operating conditions and the calculation of the weighing coefficients kA and kB occurs with the following modalities:

in region I : $kA/kB = HP\ (pA/pB) + HQ\ (qA/qB)$
in region II : $kA = 0 \quad kB = 1$
in region III: $kA = 1 \quad kB = 0$

In the first instance HP and HQ are coefficients and the exact value of kA and kB (known their ratio) is defined by imposing a normalization constraint, such as for instance that $kA^2 + kB^2 = 1$. Being the weighing coefficients kA and kB known, circuit CPS also calculates the common signal Sc according to the relation:

$$Sc = kA.sA + kB.sB \qquad (ii)$$

The signal zA and zB from multipliers mA and mB are then added in unit Σ , thus originating the combined signal Zcomb. That is unit Σ calculates a combination of the two signals received, weighed as a function of the power with which the individual signals have been received and of the respective quality and distortion (parameters qA, sA and qB, sB generated by units ST and SQ).

Furthermore, as already mentioned, the weighing circuit CPS also generates a common signal Sc as output resulting from the weighed combination of sA and sB, with the same weighing coefficients kA and kB used to combine the outputs of FA and FB. As a consequence

of it, signal Sc is representative of the response to the equivalent impulse in point Xc, so as it results from the weighed combination of the reception channels A and B.

Although the invention has been described and illustrated with particular reference to a preferred form of implementation, it is understood that it extends to cover all obvious variations and changes that will appear evident to the technician of the sector.

CLAIMS

1. Process for equalizing time-division digital signals in a radio mobile system, in which the radio signals are received by two antennae at least, featuring the fact of including the following phases:

a) making an estimate (cir) of the channel impulse response for each of the receiving branches;

b) making matched filtering of each received signal;

c) calculating some weighing coefficients (kA, kB) as a function of the information relating to the reception conditions contained in parameters relevant to each channel (pA, pB; qA, qB);

d) summing up the signals resulting from the matched filtering weighed according to the above mentioned weighing coefficients (kA, kB), thus generating a combined signal (Zcomb), and generating with a similar combination a control signal (Sc);

e) making an estimate of the numerical sequence transmitted by means of an equalization of the combined signal with the aid of said first control signal (Sc) that selects the parameters affecting the equalization process.

2. Process according to claim 1, featuring the fact that said signals received are two.

3. Process according to claim 2, featuring the fact of generating, from the channel impulse response signal (cir):

a signal (gA, gB) for the matched filtering;

a signal (sA, sB) representative of the transmission channel response in time to a single impulse;

a signal or quality factor (qA, qB) representative of the estimate of distortion undergone by the channel;

and the fact that said control signal (Sc) is obtained according to the relation:

$$Sc = kA.sA + kB.sB$$

where the weighing coefficients kA and kB are a function of the

power signals (pA, pB) and the quality signals (qA, qB).

4. Process according to claim 3, featuring the fact that said combination signal (Zcomb) is obtained as a combination of the matched filter output signals weighed according to the respective coefficients kA and kB.

5. Process according to claim 4, featuring the fact that the received signals are not correlated.

6. Process according to claim 2, featuring the fact that said matched filtering is implemented through a first transversal filter.

7. Process according to claim 2, featuring the fact that said equalization is implemented through a Maximum Likelihood Sequence Estimate implemented through the Viterbi algorithm.

8. Process according to claim 2, featuring the fact that said equalization is implemented through a second transversal filter with decision feedback.

9. Adaptive receiver in space diversity for time-division digital signals in a digital radio mobile system, including two signal-receiving and processing branches, substantially not correlated, received by the same number of antennae, where the demodulated signals of said branches, sampled and coded in a binary form, are stored in corresponding buffers, featuring the fact of including a setup circuit (PD), the inputs of which (cA, B; pA, pB) are connected to the reception branches (RFA, RFB), and the outputs of which are connected to an equalizing circuit (EQZ) for the reconstruction of the received signal, where the setup circuit (PD) generates a first control signal (Sc) and a second combined signal (Zcomb) obtained as weighed combinations of the inputs.

10. Adaptive receiver according to claim 9, featuring the fact that the reception branches (RFA, RFB) are connected to one local oscillator (OL) supplying a frequency for the demodulation of the branch received signals at least.

11. Adaptive receiver according to claim 9 or 10, featuring

the fact that said branches are two.

12. Adaptive receiver according to claim 11, featuring the fact that a circuit for the formation of the channel impulse response (CIR) and a branch matched filter (FA, FB) are connected to each branch buffer (BA, BB); and the fact that the outlet of the impulse response circuit (CIR) is connected to the inputs of a first unit (ST) and a second unit (SQ) having the outputs connected to a processing circuit (CPS).

13. Adaptive receiver according to claim 12, featuring the fact that the outlet of the impulse response circuit (CIR) is also connected to a selecting unit (SZ) the outlet of which is connected to the matched filter (FA) and to the first unit (ST).

14. Adaptive receiver according to claim 13, featuring the fact that the second unit (SQ) is also connected to the outlet of the branch buffer (BA, BB) and to a storage (MP) where the preamble sequence is contained.

15. Adaptive receiver according to claim 14, featuring the fact that the outputs of the branch matched filters (FA, FB) are connected to the inputs of the same number of multipliers (mA, mB), the other inputs of which are connected to the same number of outputs (kA, kB) of the processing circuit (CPS), and that the outputs (zA, zB) of said multipliers are connected to an adder (Σ) generating said second combined signal (Zcomb) as output, said first control signal (Sc) being generated as output by said processing circuit (CPS).

16. Adaptive receiver according to claim 15, featuring the fact that said equalizer (EQZ) contains a Viterbi processor.

17. Adaptive receiver according to claim 16, featuring the fact that said equalizer (EQZ) contains a transversal filter with decision feedback.

18. Adaptive receiver according to claim 16 or 17, featuring the fact that the antennae (A, B) of each branch are connected to corresponding receiving stages (RxA, RxB) each provided with an additional outlet connected to the weighing circuit (CPS).

Fig. 1

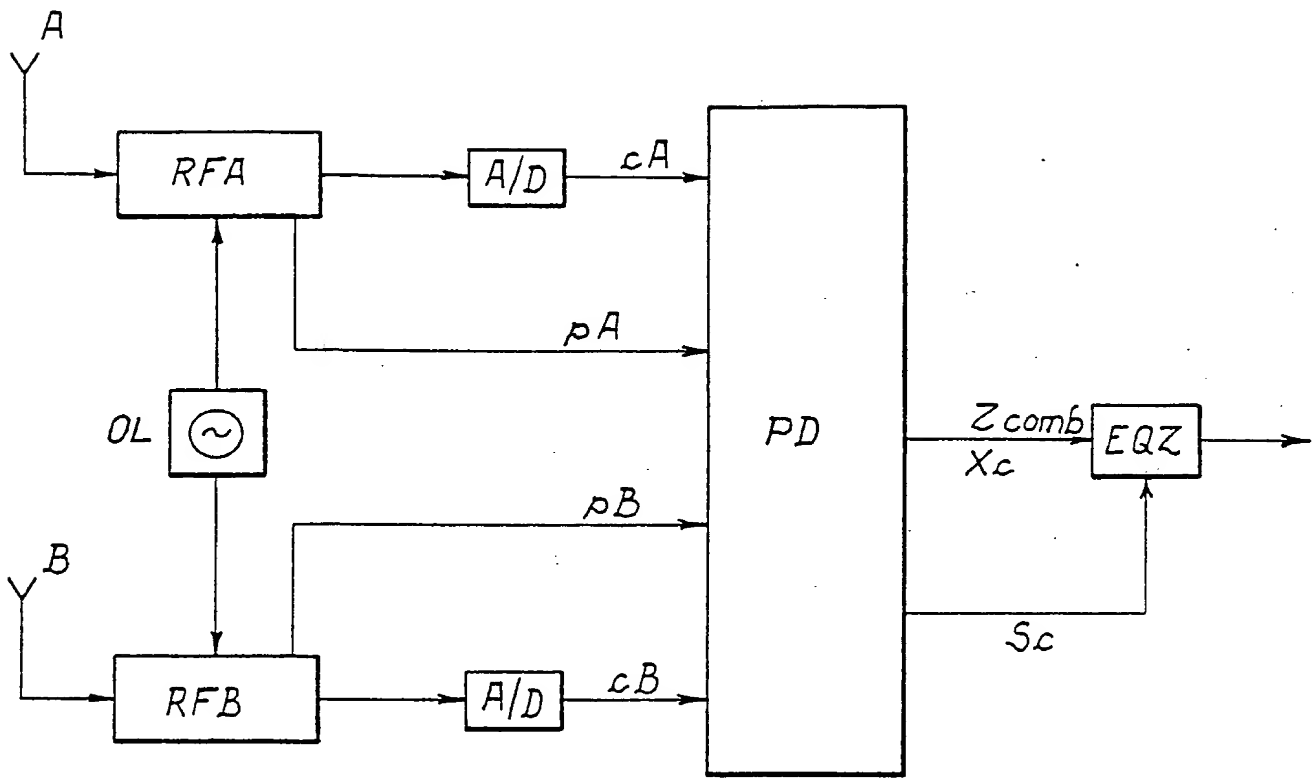
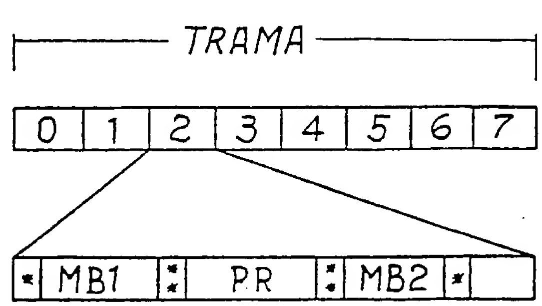

A
RFA
A/D
cA
pA
OL
PD
Zcomb
Xc
EQZ
pB
B
Sc
RFB
A/D
cB

Fig. 2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2
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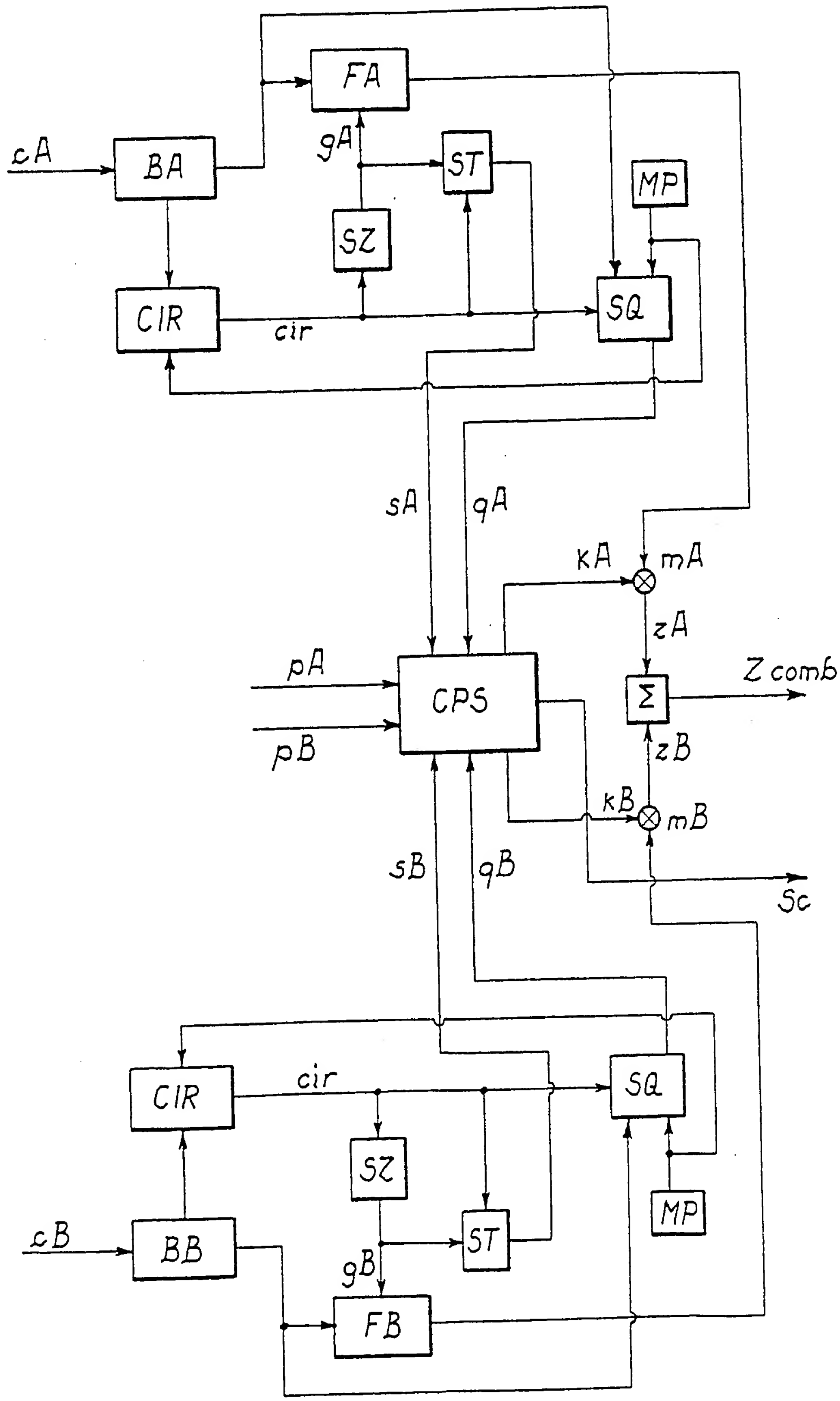
6
7
MB1
PR
MB2

Fig. 3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FA
gA
ST
SZ
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SQ
sA
qA
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Σ
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ST
gB
FB

Fig. 4

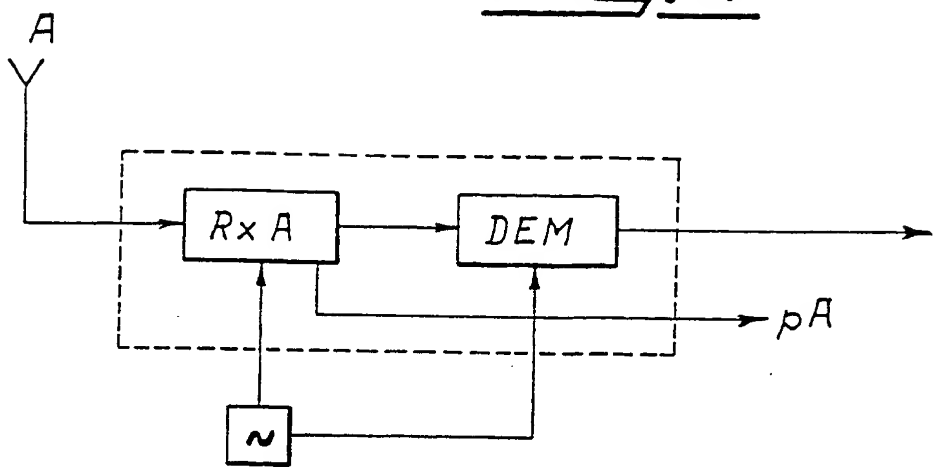
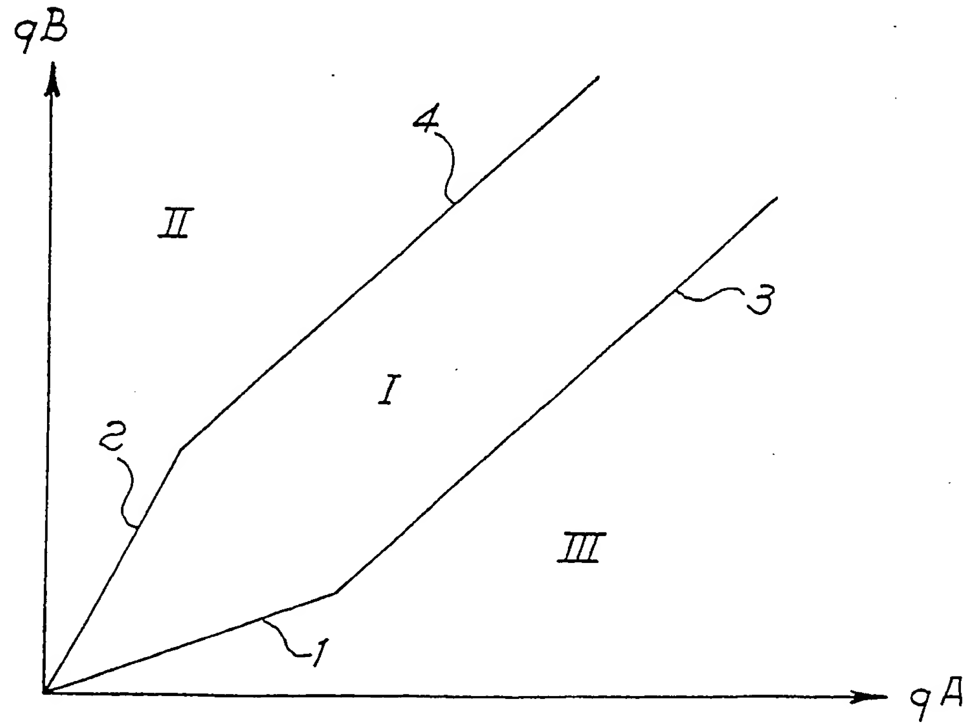


Fig. 5



INTERNATIONAL SEARCH REPORT

International Application No PCT/EP 90/00603

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: H 04 B 7/08

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	H 04 L, H 04 B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US, A, 4328585 (MONSEN) 4 May 1982 see column 2, lines 21-34; column 11, lines 5-18; figure 2 --	1-18
A	AT&T Technical Journal, volume 64, no. 4, April 1985, (New York, US), L.J. Greenstein et al.: "A simulation study of space diversity and adaptive equalization in microwave digital radio", pages 907-935 see page 913, lines 32-38; page 914, line 41 - page 915, line 2; figure 1 --	1-6,8-11
A	IEEE Communications Magazine, volume 18, no. 1, January 1980, (New York, US), P. Monsen: "Adaptive processing can reduce the effects of fading on beyond -the-horizon digital radio links", pages 16-25 see page 24, left-hand column, lines 18-34 --------	1,7

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
6th July 1990	31. 07. 90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	Mme N. KUIPER

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

EP 9000603
SA 35946

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4328585	04-05-82	None	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82